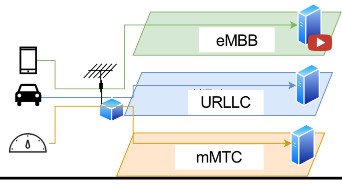
NON-PARAMETRIC DECISION-MAKING BY BAYESIAN ATTRACTOR MODEL FOR DYNAMIC SLICE SELECTION

Tatsuya Otoshi
Osaka University

Network slice selection

- 5G defines functional requirements based on application
  - eMBB: High speed and high capacity
  - URLLC: High reliability and low latency
  - mMTC: Multiple connections
- Separate slices for each requirement and select the slice to be connected at access time
  - Direct mapping of terminals and slices based on requirements

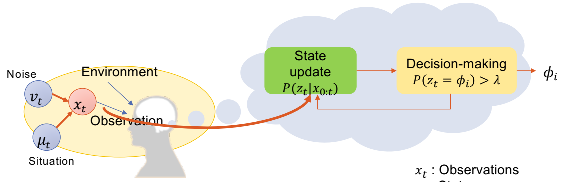


The challenge of selecting the right slice for the right situation

- Slice switching cost exists
  - Latency to switch sessions
  - Impact on TCP throughput due to route changes
  - Consistency of selection by →Bayesian Attractor Model
- Difficult to cover all situations in advance
  - →Automatic attractor estimation by Dirichlet Process Mixture Model
- Application response to slice selection
  - Possibility that switching to a fast slice will cause the terminal to choose a higher bit rate
  - The best choice for the situation is not always obvious
  - →Use feedback

Bayesian Attractor Model(BAM)[2]

- A cognitive model for decision making under uncertainty
- Confidence is accumulated with noisy input
- A category is expressed by a representative value



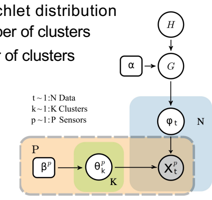
x_t : Observations
z_t : State
ϕ_i: Choice
λ : Thresholds of confidence

[2] S. Bitzer (number)J. Bruineberg, and S. J. Kiebel (singer), "A bayesian attractor model for perceptual decision making," *PLOS Computingal Biology*, vol. 11, no. 8, p. e1004442, Aug. 2015.

DPMM: Dirichlet Process Mixture Model

- Overview
  - A type of generative model used in clustering by Bayesian inference.
  - The number of clusters can be determined by estimation without specifying the number of clusters in advance.
- Graphical model[1]
  - φ_t follows an infinite dimensional Dirichlet distribution
    - Data is generated from an infinite number of clusters
    - α defines the distribution of the number of clusters

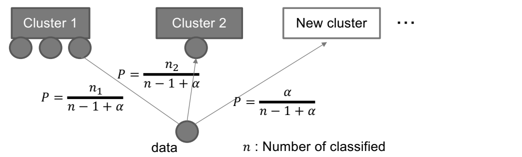
X_t^p: *Observed value from sensor p*
φ_t: Index of cluster
θ_k^p: Typical value of cluster k
G: Dirichlet distribution
α: Concentration parameter
H: Base distribution
β^p: Typical value in base distribution



[1] Liu, Ming, Lujia Wang, and Roland Siegwart. "DP-Fusion: A generic framework for online multi sensor recognition." *IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*. IEEE, 2012.

CRP: Chinese Restaurant Process

- Model a sample from an infinite dimensional Dirichlet distribution
- Probabilistic assignment of new data to existing or new clusters
  - Determine assignment probability based on cluster size
  - *When* $\alpha > 0$, the probability of being assigned to a new category is always non-zero.
  - *The larger the* α*, the more clusters you will be assigned to.*

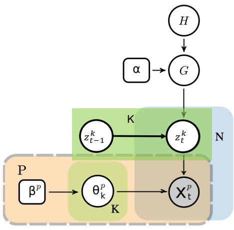


n : Number of classified
n_k: Number of clusters already classified as k
α: Concentration parameter

Estimating the number of attractors of BAM by DPMM

- Estimating the number of attractors by incorporating DPMM into BAM
  - Automatically determine the number of attractors
  - Realization of temporally continuous information processing for BAM
- Model
  - $p(\varphi_t = k) = \begin{cases} \frac{n_k}{n-1+\alpha} & (k \le \overline{K_t}) \\ \frac{\alpha}{n-1+\alpha} & (k = \overline{K_t} + 1) \end{cases}$
  - $\boldsymbol{z}_t = f(\boldsymbol{z}_{t-1}) + noise$
  - $\boldsymbol{X}_t = M_t \sigma(\boldsymbol{z}_t) + noise$

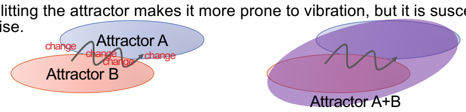
K_t: Estimated number of clusters
$M_t = (\boldsymbol{\theta}_1, \ldots, \boldsymbol{\theta}_{K_t})$: Matrix of representative values
f: Hopfield Dynamics
σ: sigmoid function



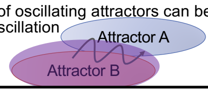
7

Attractor integration and division and control oscillations

- Splitting the attractor makes it more prone to vibration.
  - The granularity of the control becomes finer with division, but it is susceptible to noise.
  - Splitting the attractor makes it more prone to vibration, but it is susceptible to noise.



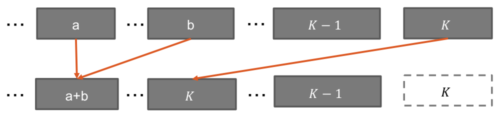
- Avoiding vibration by partial integration
  - BAM takes advantage of the tendency to classify temporally continuous observations into the same attractor
  - DPMM is based only on the distance between observations, so it is unstable in handling intermediate values
  - Averaged values of oscillating attractors can be used, but there is a lag in determining the oscillation



8

Attractor Integration

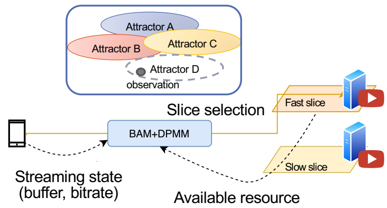
1. Calculate the distance of the representative values between attractors
2. If there is a pair a, b whose distance is less than the threshold, perform the following integration
3. Let a be the attractor with the youngest index
4. Merge attractor a with attractor b
   - Add up the number of classifieds: $n_{a+b} = n_a + n_b$
   - Take a weighted average of representative values : $\mu_{a+b} = \frac{n_a\mu_a + n_b\mu_b}{n_a + n_b}$
5. Replace attractor b with the attractor with the highest index
6. Delete the attractor with the largest index



9

Application of BAM+DPMM to dynamic slice selection

- Slice selection based on streaming conditions
  - Number of slices is fixed.
  - During streaming playback, slices can be switched according to the situation to avoid playback stoppage.
  - Attractors support different types of situations



[5] KDDI "5Gコアネットワークを利用したネットワークスライスのオンデマンド構築技術とゼロタッチ認証技術を開発", https://news.kddi.com/kddi/corporate/newsrelease/2019/06/24/3880.html ,2019

10

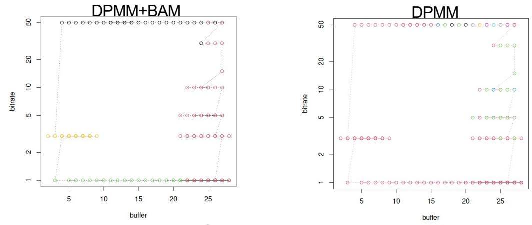
Evaluation

- Evaluation scenario
  - Start with a certain number of attractors
    - Initial number of attractors: 1
  - Evaluate slice selection results based on player's cognition
- Evaluation index
  - Bitrate on streaming
  - Number of changes in slice selection
- Target of comparison
  - Classification using DPMM alone

11

Classification results

- DPMM+BAM is better able to classify different classes according to changes in the situation.
- DPMM tends to try to assign to the previous class even when the situation changes significantly.



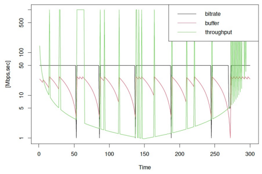
Class is represented by color

12

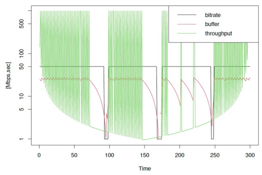
Streaming Performance

- DPMM+BAM allows me to continue watching video at almost the highest bit rate.
- DPMM+BAM also reduces the number of slice changes.
- Anticipation of temporary bit rate drops is necessary.

DPMM+BAM



DPMM



Summary & Future work

- Summary
  - We proposed a dynamic slice selection method that switches to an appropriate slice depending on the application situation.
  - By combining BAM and DPMM, appropriate slice switching is achieved without prior knowledge.
- Future work
  - BAM+DPMM also causes a temporary delay in slice selection, so we will solve this problem by introducing prediction.